Measures against Deterioration of Concrete Bridges due to Chloride Ions

Mesures afin d'empêcher la détérioration des ponts en béton sous l'action des ions de chlorure

Massnahmen gegen die von Chloridionen verursachten Schäden an Betonbrücken

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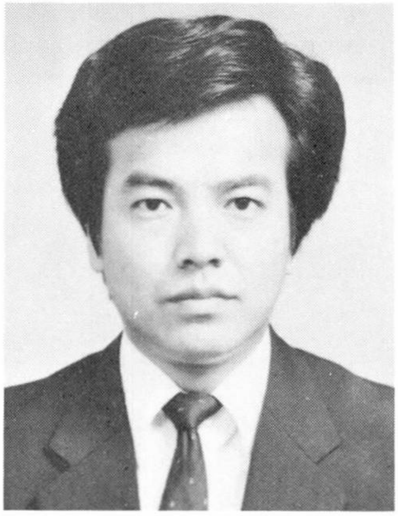

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SUMMARY

This report presents an outline of "The Design and Construction Guidelines for Coastal Structures (Draft)" based on a survey on the chloride ion and the corrosion of steel in the existing concrete bridges, and on measurement of airborne chloride ions in coastal areas all over Japan.

RÉSUMÉ

Cet exposé présente une description des "Directives de projet et de construction relatives aux structures côtières (projet)", sur la base des résultats d'une enquête portant sur les ponts existants et relative à la relation entre la teneur en ions de chlorure et la corrosion de l'acier, prenant en compte les mesures des ions de chlorure transportés dans l"air des zones côtières du Japon.

ZUSAMMENFASSUNG

Der Beitrag gibt einen Überblick über "Entwurfs- und Konstruktionsrichtlinien für Küstenbauwerke (Entwurf)", welche auf einer Reihenuntersuchung bestehender Brücken und der Beziehung zwischen Chloridionengehalt und Stahlkorrosion sowie einer landesweiten Messung der Chloridionen der Küstenluft basieren.

1. Introduction

In recent years, some concrete bridges mainly in coastal areas where the effects of splash and sea breeze are strong have exhibited cracking and delamination of concrete and corrosion of steel materials at early stages after the construction due to chloride ions penetrating into the concrete. In response to this situation, the Ministry of Construction carried out a macroscopic survey in 1982 for 920 concrete bridges located in areas within approximately 500m from the shoreline with respect to deterioration due to chloride ions. As a result, the following points were obtained.

(1) Deterioration due to chloride ions is intensive in coastal areas of Hokkaido, Tohoku and Hokuriku Regions along the Sea of Japan where the north-west seasonal wind is strong, and in Okinawa Prefecture which belongs to the subtropical region and is regularly attacked by Typhoons, as shown in Figure 1.

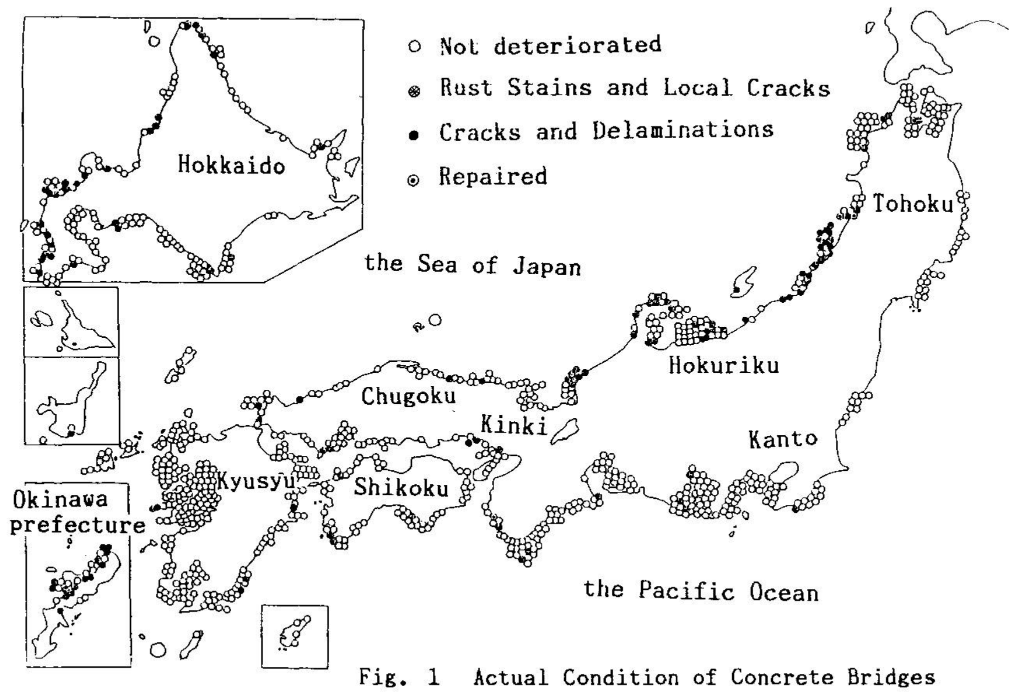


Fig. 1 Actual Condition of Concrete Bridges

(2) The majority of deteriorated bridges are located in areas within 300m of the shoreline, and those within 100m show a higher rate of deterioration.

The Ministry of Construction conducted measurements of airborne chloride ions in coastal areas all over the country as well as a survey concerning the chloride ion content in concrete and the corrosion of reinforcement of two concrete bridges which were built more than 10 years ago. This report describes an outline of "The Design and Construction Guidelines for Coastal Structures (Draft)" prepared based on these results.

2. Outline of "The Design and Construction Guidelines for Coastal Structures (Draft)"

2.1 Areas requiring measures against deterioration

The Guidelines (Draft) defines the areas requiring measures to prevent deterioration of concrete bridges due to chloride ions using the distance from the shoreline as an indicater, as shown in Figure 2. These areas are designated based on the results of a survey on airborne chloride ions as well as the above mentioned survey on the actual condition of concrete bridges.

Airborne chloride ions were measured for 3 years from 1984 to 1987 at 266 points in coastal areas all over the country. Figure 3 shows the distribution of airborne chloride ions in the country based on the survey results. The Sea of Japan coastal areas in the Hokkaido, Tohoku and Hokuriku Regions and Okinawa Prefecture, in which a number of deteriorated bridges were found, recorded a higher airborne chloride ion content. Of these areas, the Pacific coast areas in Okinawa Prefecture and the Sea of Japan coastal area in the Tohoku Region recorded the airborne chloride ion content of 0.1mg/cm^2 (NaCl weight) on the daily average for the 3 year period even at points of 300m and 100m away from the shoreline, respectively. On the contrary to these areas, the airborne chloride ion content is low in areas along the Seto Inland Sea in which the daily average for the 3 year period is less than 0.01mg/cm^2 (NaCl weight) even at points within 100m. Althouth the airborne chloride ion content in other areas such as the Pacific coastal areas and the Sea of Japan coastal areas in the Chugoku and Kyushu Regions scattered widely, it tends to become smaller at points more than 300m away from the shoreline.

2.2 Measures at the design stage

The Guidelines (Draft) indicates

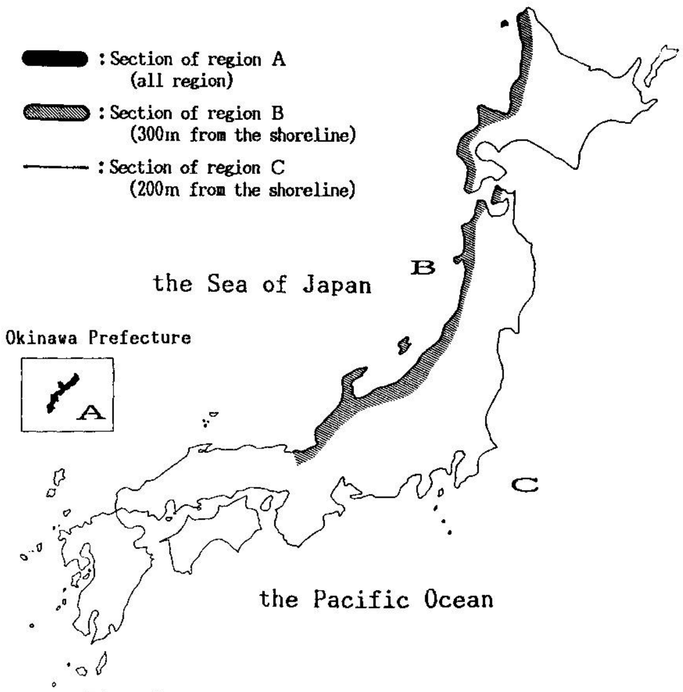


Fig. 2 Areas requiring Measures against Deterioration (Ref. Table 3)

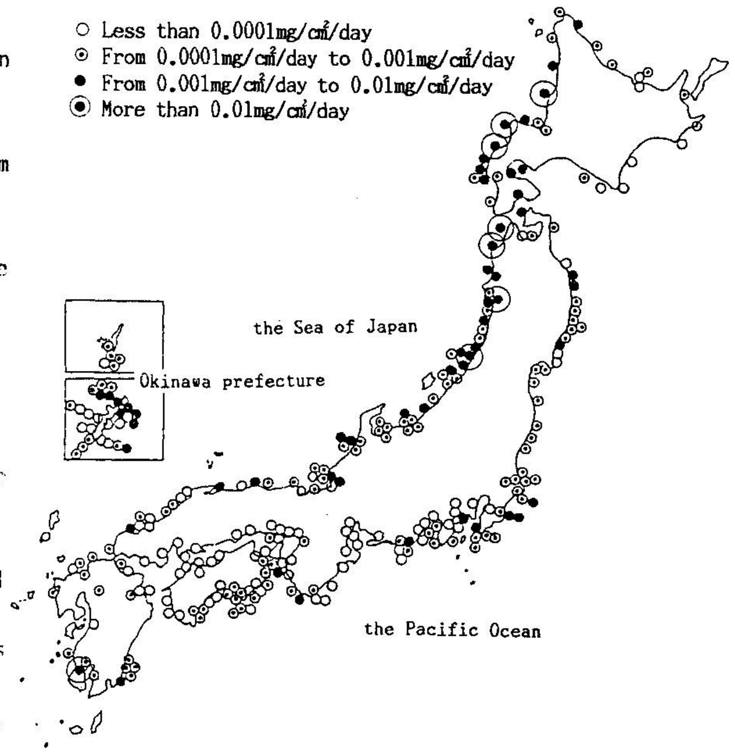


Fig. 3 Distribution of Amount of Airborne Chloride Ions (NaCl Weight)

measures for the design stage such as the shape of bridge members, the cover of reinforcement, and the materials and mixing of concrete. The basic concepts of these measures are as follows.

(1)The shape of bridge members: The chloride ions attaching to the surface of bridge members is reduced by choosing an appropriate shape.
(2)The cover of reinforcement: The chloride ions reaching the reinforcement position is reduced by ensuring appropriate cover.
(3)Concrete material: The chloride ions mixed in concrete is reduced by choosing proper materials.
(4)Concrete mixing: The quantity of chloride ions reaching the reinforcement position is reduced by using dense concrete with proper composition.

The Guidelines (Draft) also indicates that the use of coated reinforcement or the coating of concrete surfaces is effective in place of increasing the cover of reinforcement. The former measure is made to prevent directly the corrosion of reinforcement, while the latter measure is made to prevent the penetration of chloride ions into concrete.

2.2.1 The shape of bridge members

Many deteriorated bridges show that deterioration due to chloride ions concentrates on corners of members. This is because concrete placement and compaction tend to be insufficient at corners so that density of concrete is difficult to assure, and chloride ions from both the lateral and vertical directions lead to accumulate more than those in other parts. For these reasons, The Guidelines (Draft) points out that bridge members should be made to the shape with fewer corners.

2.2.2 The cover of reinforcement

Two bridges of the old Itagai and the old Dokawa located in the Sea of Japan coastal area in Hokuriku region were investigated on the cover of reinforcement, the chloride ion content, and the corrosion of reinforcement.

The old Itagai bridge built in 1978 is a reinforced concrete T-shaped girder bridge with 13.6m in length, 6.5m in width and 3 main girders, and located at the point of about 10m away from the shoreline and 5m above from the sea level. This bridge is exposed to north or north-west winds from the sea throughout the year, and to direct splash when the sea is stormy. Delamination of concrete and exposure of reinforcement were observed around the bottom of the main girders, and cracks were observed in the bridge axis on the sides of the main girders.

The old Dokawa bridge constructed in 1935 is a reinforced concrete T-shaped girder bridge with 46.6m in length, 6.2m in width and 4 main girders, and located at a point of about 40m away from the shoreline. This bridge is in an environment where north and north-west winds from the sea are predominant in winter. Concrete cracking, delamination and rust drops caused by corrosion of reinforcement were observed on the surface of this bridge.

The relation between the corrosion degree of

Table 1 Criteria for degree of Corrosion

Degree of corrosion	
A	Not corroded
B	Slight corrosion
C	Corrosion with little pittings
D	Severe corrosion with pittings

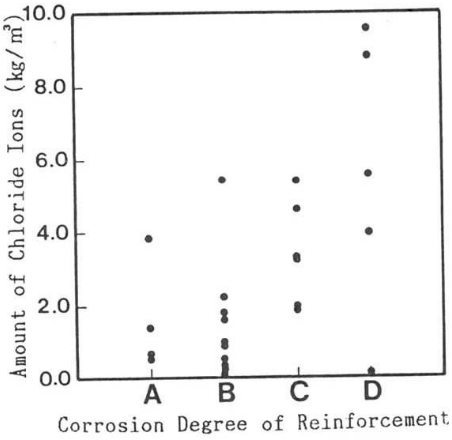


Fig. 4 Relation between Amount of Chloride Ions and the Corrosion Degree of Reinforcement (See, Table 1)

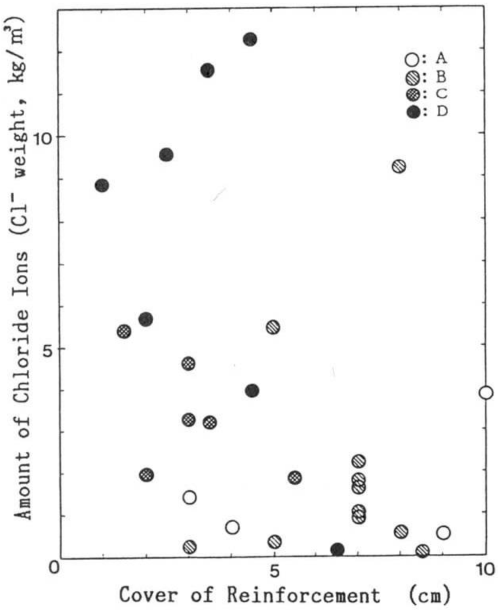


Fig. 5 Relation between the Corrosion Degree of Reinforcement (See, Table 1) and Cover of Reinforcement

reinforcement and the chloride ion content is shown in Figure 4. The corrosion degree of reinforcement was judged in accordance with the criteria shown in Table 1. The average chloride ion content at the corrosion degree C,which indicates development of corrosion, was 3.4kg/m^3 with the standard deviation of 1.4kg/m^3. Figure 5 shows the relation between the corrosion degree and the cover of reinforcement. The majority of reinforcement of which corrosion degree was C and D are in the range of the cover less than 5cm.

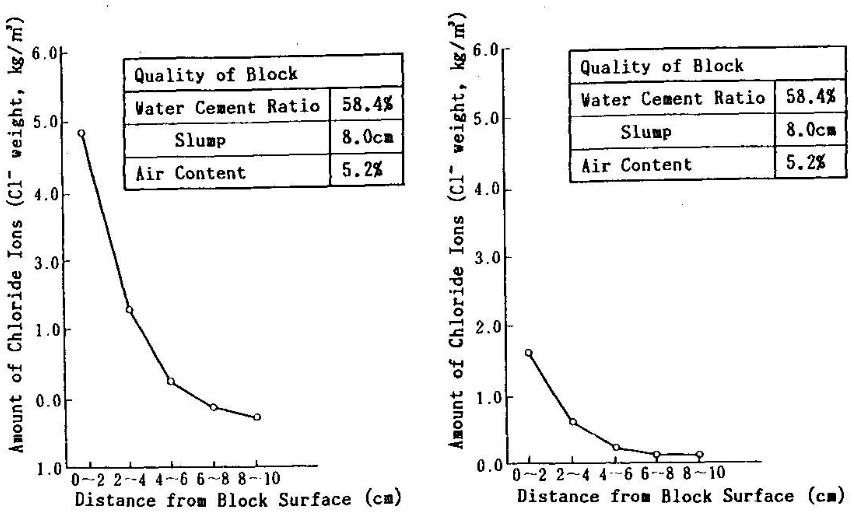
In addition, two concrete blocks and one mortar block with the dimension of 10×10×10cm were placed at 76 points, which were selected from the airborne chloride measuring points in consideration of the distance from the shoreline and other factors. Table 2 summarizes the mix proportion for each block.

Table 2 Mixing Condition for Exposing Blocks

	Water cement ratio W/C	Unit Weight (kg/m³)				Slump (cm)	Air content (%)
		Water W	Cement C	Fine aggregate	Coarse aggregate		
Mixing 1	58.4	171.2	293.0	874	959	8.0	5.2
Mixing 2	39.0	175.7	450.0	705	987	8.0	4.9
Mixing 3	57.8	203.0	351.0	1,681	–	12.5[1)]	2.3

1) Flow value

Figure 6 illustrates results obtained from this exposure test for 2 typical points. As to the block exposed at the point in the Sea of Japan coastal area in Tohoku Region where the average airborne chloride ion amounts to 0.19mg/cm^2(NaCl weight), the penetrating chloride ion of approximately 2.0kg/m^3(Cl^- weigt) leading to the corrosion development deposits at 2-4cm depth from the surface during the 3 year period. On the other hand, as to the block exposed at the point in the Pacific coastal area in Kanto Region where the average daily airborne chloride ion is 0.02mg/cm^2(NaCl weight), the quantity of chloride ions deposited at 2-4cm depth from the surface during the 3 year period is about 0.60kg/m³ (Cl^- weigt). Thus, the chloride ions penetrating into concrete is proportional to the concentration of airborne chloride ions. Based on these results, The Guidelines (Draft) sets the standard minimum cover of reinforcement as shown in Table 3.



(a) Exposing Point; the Sea of Japan Side of Tohoku Region, Exposing; 3years

(b) Exposing Point; Kanto Region, Exposing; 3years

Fig. 6 Distribution of Chloride Ions in Concrete

2.2.3 Concrete material and mixes

The Guidelines (Draft) indicates that cement to be used should be portland cement conforming JIS (Japan Industrial Standards) excluding ultra high early strength portland cement, or blast furance slag cement.

With respect to fresh concrete, The Guidelines (Draft) indicates that the quantity of chloride ions should be 0.6kg/m³ (Cl^- weight) or less for reinforced concrete members and 0.3 kg/m³ (Cl^- weight) or less for prestressed concrete members. And the following measures are indicated as to concrete mixes.

Table 3 Miximum Cover of Reinforcement of the members in the areas requiring measures

(unit: c m)

Section of region[1]	Distance from the shoreline	Kind of members: Slab	Girder	Column
A	Marine parts and from 0m to 100m	5.0	7.0	7.0
	Parts other than mentioned above	4.0	5.0	5.0
B	Marine parts and from 0m to 100m	5.0	7.0	7.0
	100m to 200m	4.0	5.0	5.0
	200m to 300m	3.0	3.5	4.0
C	Marine parts	5.0	7.0	7.0
	0m to 100m	4.0	5.0	5.0
	100m to 200m	3.0	3.5	4.0

1) See Fig. 2

(1) The standard water-cement ratio for concrete should be 0.55 or less.
(2) The standard slump of concrete should be 8cm or less.
(3) The standard unit cement quantity should be 300kg/m³ or more.

The item (1) is set to ensure the density of concrete. The item (2) is set for preventing concrete cracking associated with drying and shrinkage. The item (3) is set to ensure the plasticity necessary to spread the concrete uniformly around reinforcements.